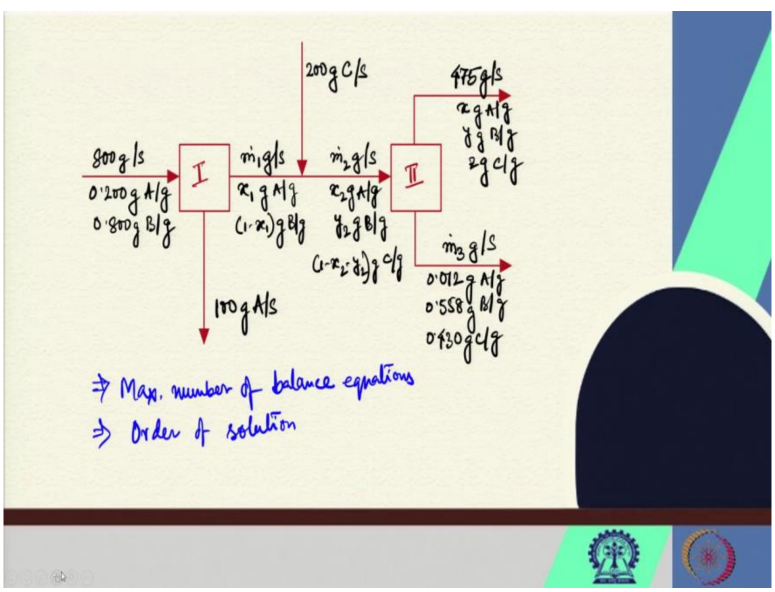
Material and Energy Balance Computations
Prof. ARNAB ATTA
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Lecture –15
Material Balance of Multiple Units - Recycle

Hello everyone, welcome back once again in the class of Material and Energy Balance Computations. We were in the material balance calculations for the multiple units, and now we will talk about the multiple units with a special feature you can consider. The point that we have discussed in the last problem that is the distillation column there you have heard the term called the recycle. So, we are recycling certain stream into the column again and the continuous operation was happening there.

So, the recycle is also a part of this multiple unit balance. So, you have seen in the last problem when the recycle was happening the condenser or the reboiler was acting a kind of a splitter or bifurcation point. So, in this lecture we will introduce that concept its utility and will see with the help of an example how that is also balanced or how the material balance are typically done in such recycle systems.

(Refer Slide Time: 01:47)



So before that let us have a quick recapitulation of whatever we have done and in this problem we will not solve anything we will just outline the strategy and try to understand that whether it is following your methodology that you have already developed for solving such problem. Now here the problem statement is very simple we again the point is that will not numerically solve it but we will see that how such problem based on whatever we have done in couple of examples if we can quickly answer this strategy or not.

So, here we have 2 unit system in which one feed was coming in of known composition A and B where say product A is separated partly separated the rest of the stream is further mixed with another component which is C. So, we have a mixing point here this whole mixture is fed into another unit where we have 2 streams of one stream having known composition but the mass flow rate is unknown the other stream the mass flow rate is known but we do not know the composition.

So, say someone has levelled it like this the unknown parts here we have unknown the mass flow rate of the rest of the stream that is coming out from the unit 1 after 100 kg of A per second being of separation. So, the rest is having a composition which is x_1 grams of A per gram of this stream and the rest is B because here initially there was A and B. In the mixing point or the mixing junction we have another component C being introduced here.

So, that means this mixture stream is having a molar flow rate of $\dot{m}_2$ and molar composition is x_2 gram of A per gram of this stream the composition of B is y_2 gram of B per gram of this stream and that means $1 - x_2 - y_2$ which is the rest is the C the unknown composition. Say, someone has written like this x, y and z respectively for A, B and C where the mass flow rate is known in other case the mass composition the mass fractions are known but not the flow rate.

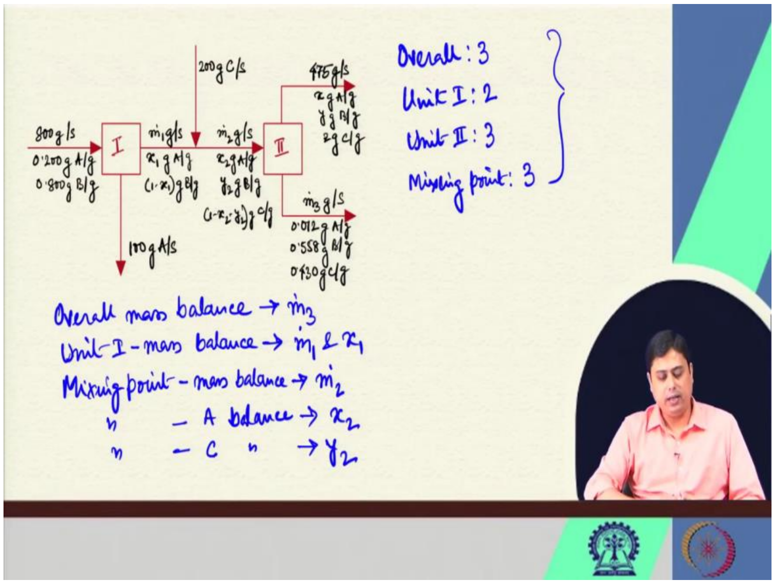
So, our job here is to find out that what are the maximum number of balance equations we can write for these systems and what should be the order of solution. The sequence of the equations that we should write minimizing the calculation effort, which will give us the solution. So, first of all the strategy is that, we should immediately look for the overall system degree of freedom analysis whether this problem is solvable or not.

Now if we look at it our system boundary for the overall case is this one where we have several intersecting lines. Now in this stream we have everything known this stream is known, this stream is known, here we have one unknown and here apparently we have 3 unknowns x, y, z but this x, y, z if somebody considers that these are the 3 unknowns there some issue will happen because this z is dependent on x and y.

So, z is basically 1 – x – y. So, basically if someone replaces here this relation like we have written here then what will happen the number of unknowns here would reduce to 3 instead of 4. So, here we have 3 species, we have 3 unknowns which means the degree of freedom is 0 and the problem is solvable. So, we should proceed in solving the problem. Now coming to the question of order of writing the equations, the sequence of writing the equations.

So, that we can minimize our calculation effort which means we will try to avoid as much as possible the solution of simultaneous equation because it is always easier to solve a equation with one unknown. So, what we will do.

(Refer Slide Time: 08:25)



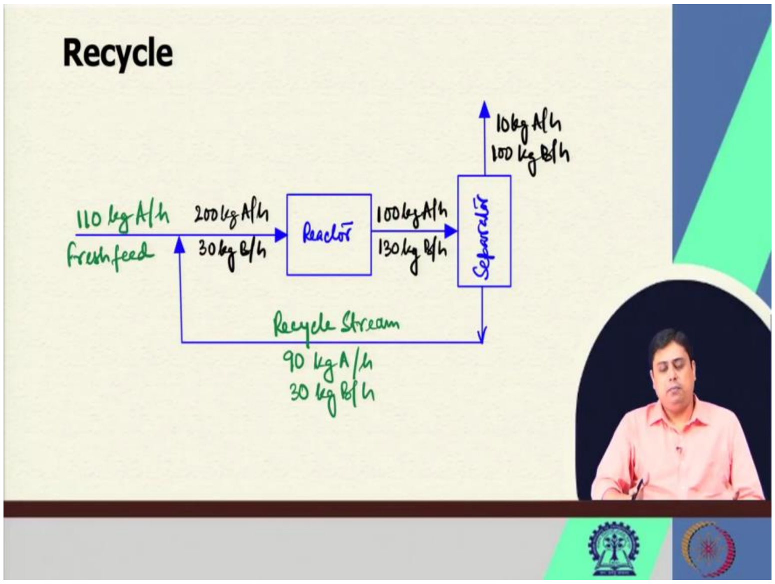
So, now the maximum numbers of balance equations that we can write we can clearly identify that for the overall process, we can write 3 balance equations for unit 1 we have 2 species.

So, we can write at max 2 independent balance equations. For unit 3 here we have 3 species. So, we can write 3 independent material balances. The mixing junction similarly we have 3 species and 3 balance equations we can write. So, the solution order would be say if I write the overall mass balance we can easily find out what is $\dot{m}_3$ because for the overall mass balance if you consider this as overall system boundary these 2 are known m_3 is unknown.

So, we can quickly find out what is the $\dot{m}_3$. Then if we look at unit 1 we can write the mass balance there, where it would involve this $\dot{m}_1$ and x_1. The mixing point here if we try to write the mass balance that is the mixing point here we will see that we can find out $\dot{m}_2$ for this case. For the mixing point if we write the A balance, we get the value which is x_2 and with the help of C balance because C is there only in 2 streams.

So, that is why it is convenient to write for C to minimize the number of calculations we can have the value y_2. So, the point is that this is the way we should look into the problem and quickly find out its solution strategy before even going into the details of calculation that we quickly find out from these understandings that which unit we should be targeting at first, which will start the calculation and with the help of those known values will proceed further for the subsequent calculations.

(Refer Slide Time: 12:05)



So, now as I mentioned recycle is basically a part of these multiple units because see any typical reaction is not completely converted from reactant to product in a single pass or even say 100 %

conversion of any reactant to product is very rare and say your reactant is costly, is precious. Now that means if the reaction is not 100 % completed with the product stream there will be some amount of reactant.

Now if it is too costly to discard with the product that means you have to separate it. Now there comes the point of economy whether the separation and the cost of your reactant this comparative study is important. Say in this analysis you realize that separation is much easier or say cost effective than discarding the rest amount of the reactant which is precious or costly. So, in that case what will happen, you would separate it and then again recycle back the unreacted reactant and mix with the fresh feed.

And this combination will further be charged into the reactor. So, this is the whole point of getting into the recycle stream are other several utility of recycle streams as well that when you try to control a particular process variables there this recycling of certain reactant or effluent is necessary. So, say a system that looks like that it is shown in the schematic or in the flowchart. That here now we are clearly writing that this is the fresh feed coming into the system the overall process.

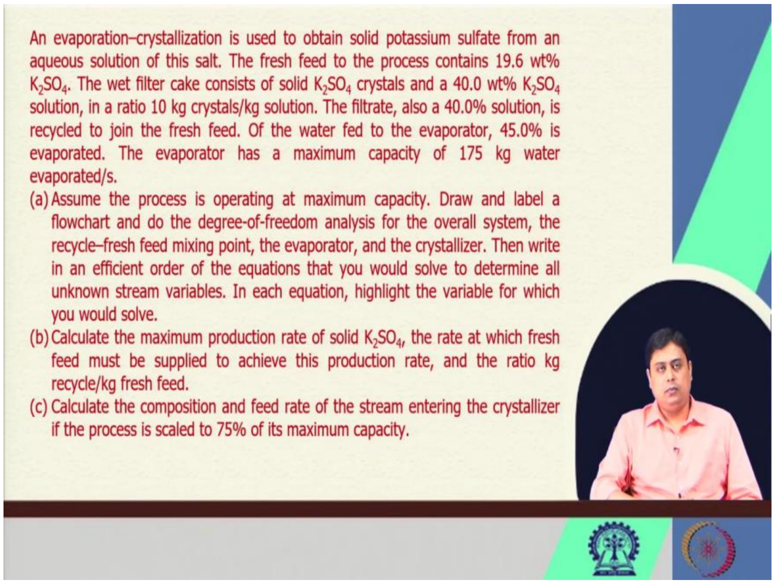
Because the overall process that starts is something like this. The recycle stream remains inside the overall process it is neither coming out of the system boundary or the overall system boundary not intersecting not intersecting the system boundary. So here you can see that for this system boundary or the overall system boundary we have 110 kg of flow rate fresh feed that is coming in and 110 kg that is going out per hour of this whole overall process.

Inside the system there is recycling happening but it is not affecting the overall process. So, now if you look at it the thing that you would see that once it is initially the fresh feed is there the reactor is intermediate step or where the reaction is happening. So, now you see that each and every step we have the overall balance concern. So, here we have 120 kg of recycle stream mixing with 110 of fresh feed making it 230 kg of the mixed stream going into the reactor.

230 kg is coming out from the reactor of which 110 kg is being taken out as the product and 120

kg again recycled back. So, without any accumulation in the system this recycle stream works. Here 110 kg/h comes in and 110 kg/h goes out of the system. So, there is no net accumulation but there is recycle stream. So, the scenario say would be much easier to further understand it if we look at the problem statement.

(Refer Slide Time: 17:15)



Now what happens in a evaporation crystallization system that if we have some aqueous solution in evaporator or evaporator crystallizations means we have 2 unit system you can consider it in this way one is the evaporator the other one is the crystallizer. So, in evaporator some fresh say some aqua solution comes in where it is concentrated, the concentrated solution goes into the crystallizer where it is crystallized and filtered.

So, that means there is the filtrate that can be recycled, because this aqueous solution sometimes what happens during the filtration and all these processes as the utility of recycles as well that the concentrate, if it is too thicker then, it is difficult to handle or to filter it. So, in such cases also the recycle streams helps into diluting the streams but in this case the scenario is bit different. So, here we have evaporation and crystallize in 2 chambers it is being concentrated an aqueous solution that comes in the evaporator it is concentrated.

The concentrated part is going into the crystallizer and in the crystallizer it is crystallized with some solid part and the rest which is the filtrate it is further recycled and the filtrate the crystal part the solid part is taken out as product. So, here is a system where the solid potassium sulphate is obtained from its aqueous solution. So, fresh feed that contains 19.6 wt % potassium sulphate is processed the wet filter cake consists of solid K_2SO_4 crystals and 40 wt % K_2SO_4 solution in a ratio of 10 kg crystals per kg of solution.

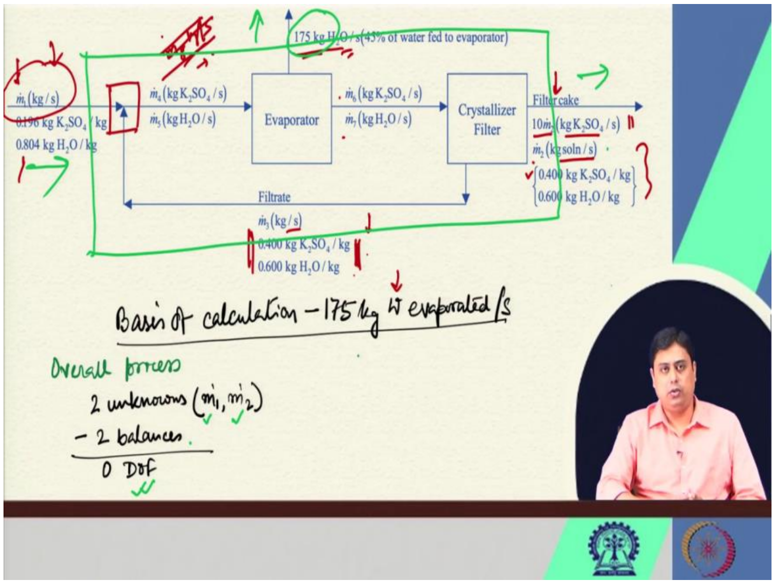
So, that means the product that you are getting if the K stands for the potassium sulphate. So, here what is happening that you are getting the mixture of product where you have the ratio that if you are getting 10 kg of crystals there would be one kg of aqueous solution that contains 40 wt % of K_2SO_4, the filtrate also a 40 wt % solution is recycled and is joined with the fresh feed, of the water fed to the evaporator 45 % is evaporated.

The evaporator has maximum capacity of 175 kg water evaporated per second. So, from the evaporator the water that is evaporated at if it works the whole system works at a maximum capacity that would be 175 kg water evaporated per second. So, if we assume the system is operating at maximum capacity we have to draw and level a flow chart we have to do the degree of freedom analysis for the overall system the recycle fresh feed mixing point the evaporator and the crystallizer.

Explicitly all the subsystems or the systems of this overall process are mentioned here and then the steps that we have followed we have to write an efficient order of the equations that we will solve to determine the all unknown subsystem variables. In each equation we have to highlight the variables for which we will solve that equation and then there are some additional question has been asked. So, we will come to this this B and C part at a later stage.

Because for any additional parameter calculation we have to at first understand or we have to at first estimate all the unknown variables that is levelled on the flowchart.

(Refer Slide Time: 22:48)



So, first of all let us understand the system again that I have told you the concept. So, here we have a fresh feed of certain amount that comes in goes into the evaporator where evaporator job is to vapourise the water concentrate it sent to the crystallizer where it is also being filtered. The filter cake as I mentioned contains the amount of solid crystal + the aqueous solution and that aqueous solution has a certain composition that is also mentioned in the problem statement.

The filtrate is also of known composition is recycled and mixed with the fresh feed and the system and the process continues. So, how do we treat this recycle stream? The recycle stream here we can see we have seen earlier as well in this case the aqueous solution and this recycle concentration the filtrate concentration has not changed and also where it is mixed with the fresh feed there is an additional subsystem or system that we must consider as mixing point.

So, the recycle introduces an additional subsystem or system in the process which is the mixing point and we have to be careful about the stream composition the recycle stream composition. So, now if we try to level it we see that we have unknown amount of aqueous solution that is coming into the system we also do not know how much of the product is being extracted but we know that at maximum capacity of this whole process 175 kg of water per second is evaporated.

So, our basis of calculation for this problem would be the logical assumptions that based on its maximum capacity of operation that the basis of calculation is 175 kg water w stands for the water evaporated per second. Based on this maximum capacity what could be the fresh feed intake and what could be the output we calculate that. So, based on this basis of calculation again since we have per second we check the unit consistency of all the level unknown variables and we write accordingly that it is in that kg per second at the mass flow rate.

And also these compositions are provided based on the mass fractions. So, here again one can always write that like kind of this convention that we have say m_7 or say m_8 kg/s out of which we have unknown composition of $\dot{m}_4$ and $\dot{m}_5$ kg K per kg of this stream but that would introduce another unknown variable which is definitely linked that is $m_4 + m_5$ would be m_8.

And in that case m_4 the units would change that is kg K_2SO_4 + kg of this m_8 stream, to avoid that here it is not assumed any further unknown variable to reduce the numbers. So here directly it is written that m_4 and m_5 are the kg of component that is flown in the stream. Similarly $\dot{m}_6$ and $\dot{m}_7$ are there. Now here the problem statement can be convoluted like this that it is mentioned the weight filter consists of solid K_2SO_4 crystals and a 40 wt % K_2SO_4 solution and their ratio is given which means the ratio was 10 kg crystal per kg of solution.

That means if we have 10 m_2 or say the m_2 is the kg solution the aqueous solution per second we have 10 m_2 of this K_2SO_4 potassium sulphate. And in this aqueous solution the concentration is mentioned here that the 40 % weight fraction of K_2SO_4. So we have in this m_2 we have 0.4 kg of K_2SO_4 per kg of this aqueous solution and the rest is water. The filtered composition is similarly mentioned here in the problem statement that the filtrate also a 40 % solution.

Now I told you earlier that when it is explicitly further not mentioned as wt % but in the previous statement it is mentioned at wt % you can safely consider that this is also a wt % composition. So, it is written in that way. So, based on this basis of calculation we proceed we look into the overall process. For the overall process we see that we have basically 2 unknowns, one is $\dot{m}_1$ the other one is $\dot{m}_2$.

Because this is my or this is our overall system boundary where we have 1 input stream and 2 output streams of which one is known and here m_2 is unknown the compositions are known. So, that means we have $\dot{m}_1$ and $\dot{m}_2$ are the 2 unknowns we have 2 species here. So, we can write 2 independent balances, material balances. So, our degree of freedom for the overall process is 0 which means the problem is solvable.

Do not forget to do this check and then start doing the calculation because sometimes it would be deceiving, the information that has been given you may start directly with the calculations and then lands up nowhere, if you had not checked earlier whether the degree of freedom is 0 or not. So, we will continue this discussion in the next class as well on this recycle specifically focusing on the recycle stream.

We will solve couple of problems in the next couple of classes. Till then try to solve this problem at your own because everything here has been shown in the earlier problems. Here it is the mixing point only it introduces a mixing point and you apply like the previous problems, the similar methodology to solve this problem. We will solve it in the next class, till then Thank you for your attention.